The geomorphology and soils of the Yoongarillup Plain in the Mandurah—Bunbury coastal zone, South-western Australia: a critical appraisal

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Abstract

The term Yoongarillup Plain, and a suite of associated landform-soil units, to date, have been inconsistently applied to landform units and inaccurately mapped on the Swan Coastal Plain in the Mandurah to Bunbury area of SW Australia. The term Yoongarillup Plain should be applied, geomorphologically, in a more restricted sense to refer to the plain between Mandurah and Bunbury that is underlain by fossiliferous limestone mantled by a variable but relatively thin blanket of quartz sand. The term should not be applied to the low undulating terrains and plains developed within the Quindalup Dunes, or to shoreline landforms of the Peel-Harvey system developed by estuarine processes. With regard to the soil groups, it is suggested that the term Yoongarillup Association be applied to surficial materials of the Yoongarillup Plain as defined in this paper, and that the materials underlying the Quindalup Dunes, the estuarine fringes, and the other plain geomorphic units of Holocene age in the region be excluded from the Yoongarillup Association.

Introduction

A geomorphic unit (the Yoongarillup Plain) and a suite of associated landform-soil units form part of the Swan Coastal Plain in the Mandurah to Bunbury area of SW Australia (Churchward & McArthur 1980, McArthur & Bartle 1980). Information on the Yoongarillup Plain, and the landform-soil subdivisions within it, subsequently has been used to outline land use potential and vegetation habitats/associations, and to delineate areas for conservation (McArthur & Bartle 1980, Churchward & McArthur 1980, Heddle *et al* 1980, Trudgen 1984). It also can be anticipated that the definition, distribution and relationships of the Yoongarillup landform and soil units may be used to resolve the Quaternary history of the Swan Coastal Plain in this region.

Data from recent investigations (Semeniuk 1990), however, are incompatible with the descriptions and mapped distribution of the Yoongarillup landform and soil units of McArthur & Bartle (1980), and hence there is a need for discussion and some reconciliation of the varying data. These issues are important because the present description and definition of the Yoongarillup landforms and soils in the literature are misleading, and may result firstly in incorrect interpretations of the Quaternary evolution of the Swan Coastal Plain, and secondly to inappropriate decisions on land use potential and conservation in this region. For instance, the current definition of Yoongarillup Plain by McArthur & Bartle (1980) and Churchward & McArthur (1980) actually encompasses a variety of different landform units, and is more complex than presently indicated, and thus the real diversity of the terrain is not fully appreciated. This aspect would be important in the assessment of conservation potential of any landform units within the Yoongarillup Plain in the region.

The objectives of this paper therefore are: 1) to provide a brief review of the definitions and concepts of Yoongarillup landforms and soils; 2) to provide field information to compare with these current definitions; 3) to discuss any differences in order to constructively clarify the definition of the Yoongarillup landform and soils so that the units may be of practical and scientific use to later workers; and 4) to suggest aspects that require further research or clarification. The data for this paper are based on the published literature on the Leschenault Peninsula area (Semeniuk & Meagher 1981a, Semeniuk 1985), information on calcrete in the region (Semeniuk & Meagher 1981b, Semeniuk & Searle 1985a, Semeniuk 1986), a description of coastal landforms in the Peel-Harvey estuary (Semeniuk & Semeniuk 1989a), fieldwork, and various drilling programs undertaken in the region using a reverse air circulating coring device. The drilling program culminated in some 250 cores, to depths of 30 m, the data from some of which are presented here. Locations of drill sites are presented in Semeniuk (1983, 1985, 1990), C A Semeniuk (1988), and Semeniuk & Semeniuk (1990).

Previous work

The term "Yoongarillup" appears first to have been used by McArthur & Bettenay (1958) to refer to Yoongarillup Sand, a sand unit which they assumed to be a surficial soil, overlying fossiliferous limestone in the

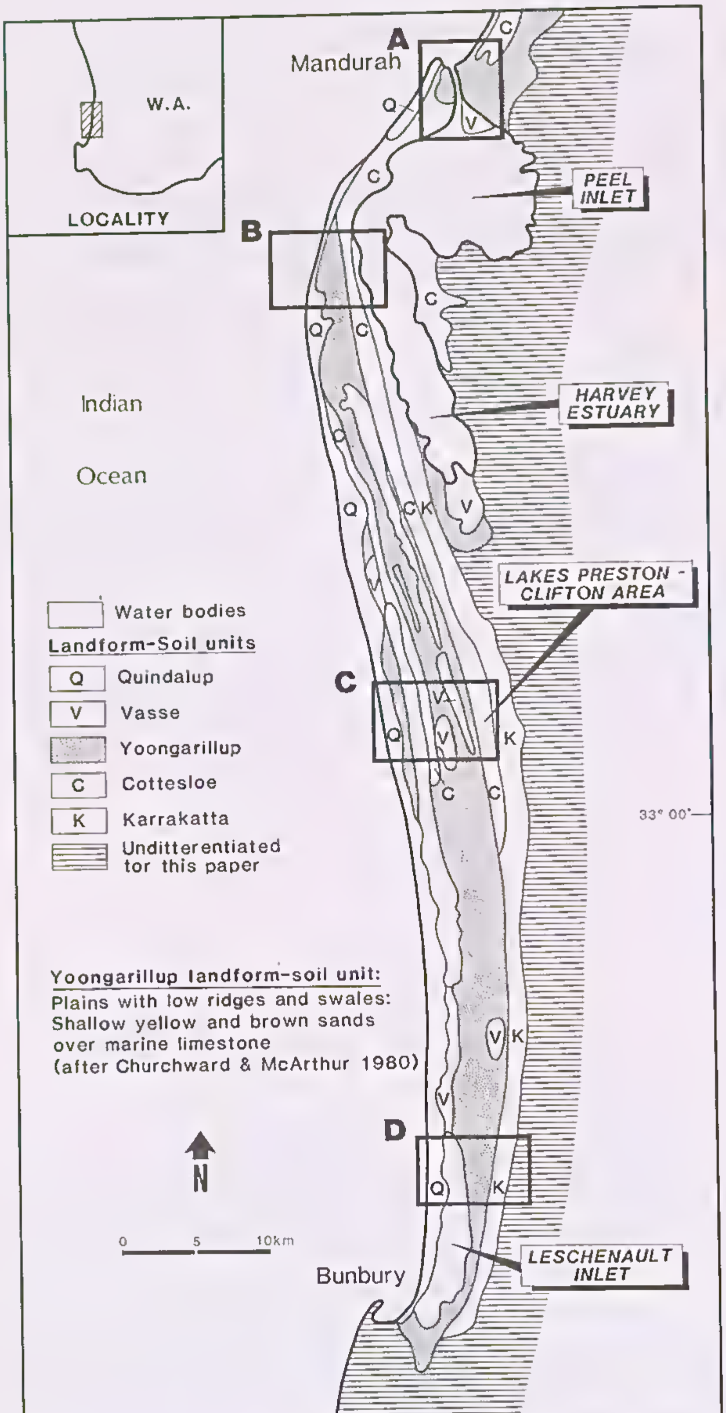

Figure 1 Location of study area, distribution of the Yoongarillup Plain after Churchward & McArthur (1980), and location of selected small study areas shown in Figure 2.

Busselton area. Later, Bettenay *et al* (1960) used the term Yoongarillup Association to refer to soils and surficial materials overlying fossiliferous limestone occurring in the areas south of Bunbury. Thus in the areas south of Bunbury, because it was overlying fossiliferous limestone instead of aeolian limestone, the Yoongarillup Association replaced (and by implication, was equivalent to) the Cottlesloe Association of the Swan Coastal Plain north of Bunbury. At this stage the term Yoongarillup appeared to be confined to the region south of Bunbury. Churchward & McArthur (1980) used the term Yoongarillup unit, as a landform-soil unit, to denote the plains between Mandurah and Bunbury underlain by marine limestone, thus extending the original term to areas north of Bunbury (Fig. 1). Churchward & McArthur (1980) also noted that estuarine deposits, referred to the Vasse unit, could be clearly separated from Yoongarillup units in this region.

McArthur & Bartle (1980), in an investigation of the terrain between Mandurah and Bunbury, used the term Yoongarillup to refer to the soils and landforms in this region. But the term now was used in a geomorphic sense (*ie* Yoongarillup Plain) to refer to the relatively flat low-lying terrain, or plain, underlain by fossiliferous limestone on the western part of the Swan Coastal Plain, and in a soil sense (encompassing various soils and surfical units notated by alphabetic abbreviations) to refer to the suite of soils and surficial materials on this plain. The definitions of the Yoongarillup Plain and its associated suite of soil units as described by McArthur & Bartle (1980) are presented below, because it is important to compare these definitions and the areas mapped by McArthur & Bartle (1980) with descriptions of materials actually occurring in the study area.

According to McArthur & Bartle (1980), the Yoongarillup Plain (geomorphic definition) is a flat terrain with minor ridges and swales; there are depressions with swamps and lakes, and the terrain is underlain by marine fossiliferous limestone, with a capping of secondary calcite, overlain by siliceous sand. The landform-soil units of McArthur & Bartle (1980) are:

- Ys grey sandy surface, a light grey subsoil, and a thin layer of yellow sand resting directly on limestone at 30-40 cm.
- Yls bare limestone.
- Yb swamps in depressions, often drained; dark brown loam over a layer of calcareous marl which then passes into shell beds.
- Ysp stony plains in slight depressions; black loam over limestone; much outcrop and loose rock.
- Pg upper terraces fringing lakes; grey siliceous sand, with a thin layer of yellow sand resting directly on soft fossiliferous limestone at 20-30 cm.
- Ps lower terrace fringing lakes; black loam overlying marl or shell beds at about 30 cm.
- Pr benches fringing Peel Inlet and Harvey Estuary; includes saline flats, sandy terraces, and sandy beach ridges.

The Yoongarillup Plain as a geomorphic unit

As presently defined and shown on maps (Churchward & McArthur 1980, McArthur & Bartle 1980), the Yoongarillup Plain appears to encompass several geomorphic units underlain by various stratigraphic sequences. These units, their stratigraphic sequences, and the study sites of this paper are (Fig. 2, Table 1):

1) an extensive, shore-parallel tract of relatively low-lying terrain underlain by fossiliferous limestone with negligible cover of quartz sand (site 6, Fig. 2B);

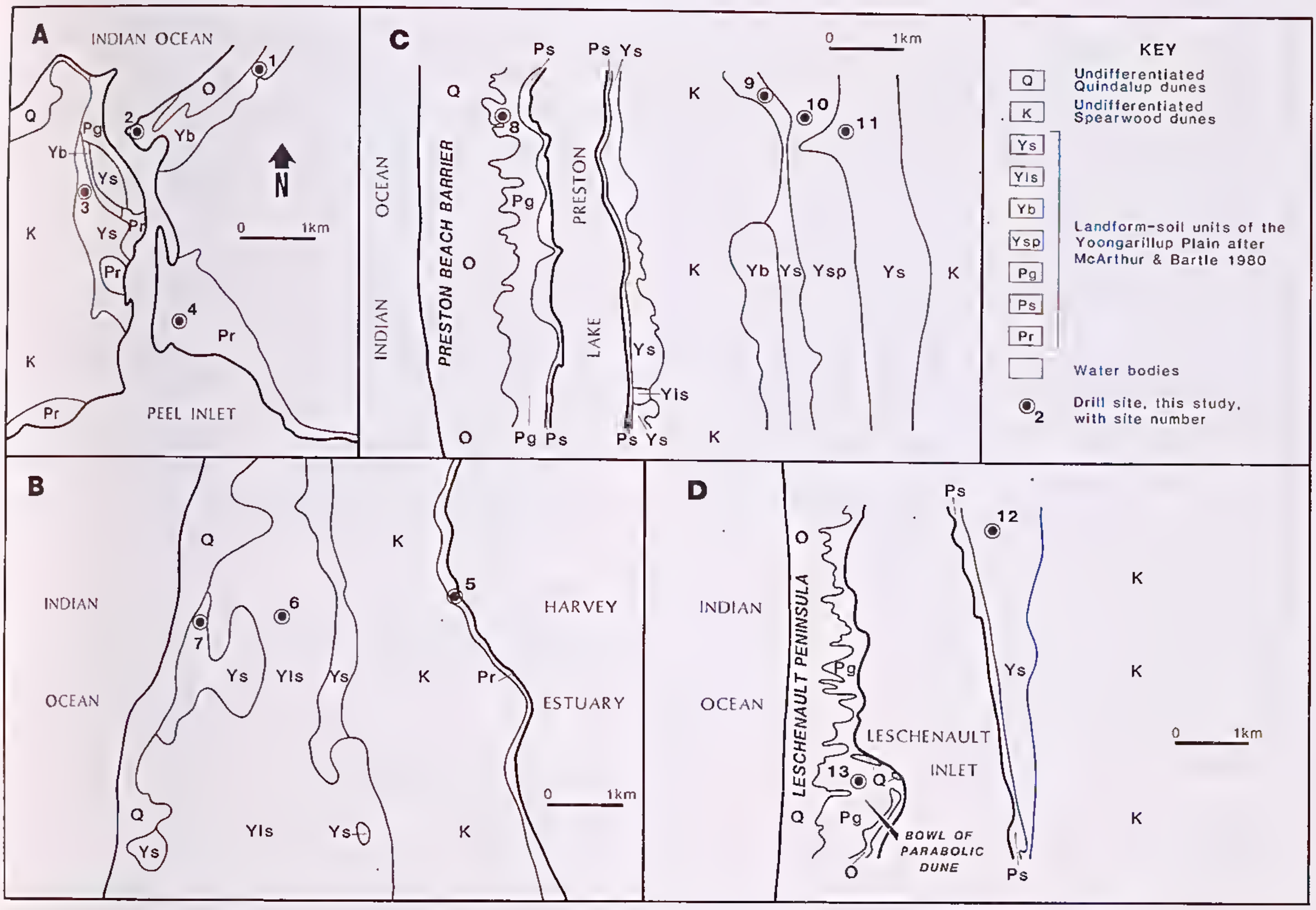

Figure 2 A, B, C, & D: Distribution of landform-soil units drawn from McArthur & Bartle (1980) in the selected small study areas, and location of drill sites 1-13 of this study. Key to landform-soil units of McArthur & Bartle (1980) is listed in text. Description of drill sites presented in Table 1.

2) an extensive, shore-parallel tract of relatively low-lying terrain underlain by fossiliferous limestone with variable cover of yellow, brown to grey quartz sand (sites 7 & 12, Fig. 2B,D);
3) plains underlain by quartz sand, with no underlying fossiliferous marine limestone (site 9 & 11, Fig. 2C);
4) wetlands (damplands, sumplands and lakes, using the terminology of C A Semeniuk, 1987), with various types of sedimentary fill of various ages (site 10, Fig. 2C);
5) coastal beachridge ribbons overlying riverine sand deposits (site 2, Fig. 2A);
6) geomorphically degraded terrain of Quindalup Dunes in the Leschenault Peninsula area (site 13 on Fig. 2D) referred to as the woodland plain (Semeniuk & Meagher 1981a), and equivalent geomorphic units on the Leschenault-Preston barrier (Searle & Semeniuk 1985) in the Preston Beach area (site 8, Fig. 2C); and
7) various types of estuarine Holocene shoreline terraces and flats (Semeniuk & Semeniuk 1990) in the Peel-Harvey system (sites 1, 3, 4 & 5, Fig. 2A,B).

The Yoongarillup Plain could be viewed as polygenetic in origin. However, it is more likely that the term has been applied to landform units inconsistently (Table 1). That is, some of the landform components of the Yoongarillup Plain described by McArthur & Bartle (1980) belong to previously defined and accepted landform-soil units. For instance, the Quindalup Dunes along the full length of the Leschenault-Preston barrier consist of landforms that range from active, mobile, unvegetated dunes, to high-relief dunes fixed by vegetation, to degraded, fixed dunes, which grade to a plain. This is apparent firstly in the differentiation of the Quindalup Dunes by McArthur & Bartle (1980) into units of Q1, Q2, Q3, and Q4, and secondly in the recognition by Semeniuk & Meagher (1981a) that the woodland plain is the end product of dune terrain degradation. All these Quindalup landform units are inter-gradational, and are underlain by the same stratigraphy—the Safety Bay Sand with thin calcrete sheets and buried soils, and the estuarine Leschenault Formation (Semeniuk 1983, 1985). Use of the term Yoongarillup Plain by McArthur & Bartle (1980) on the Leschenault Peninsula and on the barrier in the Preston Beach area therefore allocates a degraded Holocene Quindalup Dune terrain to a geomorphic unit defined to be a plain underlain by very shallowly buried Pleistocene limestone.

Table 1

Description of landforms and stratigraphy at the study sites, and correlation with units of McArthur and Bartle (1980)

Study site (locations shown on Fig. 2)	Units of McArthur and Bartle (1980)	Landform description (this paper)	Stratigraphy[1] (this paper)	Comments
1	Yb	Linear lowland (wetland)	Mud and shelly mud 3 m thick, overlying limestone	Stranded estuarine embayment
2	Yb	Low coastal beachridge plain	Dune sand (Safety Bay Sand) 1-2 m thick overlying Becher Sand, overlying coarse, gravelly quartz sand	Holocene coastal dune deposits overlying seagrass deposits and river sediments
3	Ys	Low plain of sand ridges and hummocks and intervening depressions fringing the estuary	Sand and shelly sand overlying estuarine deposits 4-20 m thick, and an irregular basement of limestone at depth which locally crops out; thin calcrete sheet within 1 m of surface	Stranded channel shoal complex formed during a higher Holocene sealevel
4	Pr	Extensive flat fringing the estuary	Shelly sand and mud, 1-4 m deep, overlying an irregular basement of limestone, which locally crops out	Relict tidal delta complex formed during a higher Holocene sealevel; Churchward and McArthur refer this unit to the Vasse, while McArthur and Bartle refer it to Pg of the Yoogarillup Plain
5	Pg	Narrow platform fringing the estuary	Veneer of mud and muddy sand overlying several metres of sand; aeolian limestone at depth	Shore-fringing marginal platform
6	Yls	Undulating stony plain with parallel low ridges and swales	Veneer of humic and yellow quartz sand on aeolian limestone 1-4 m thick overlying marine limestone	Nearly conforms to the definition of Yls except that surficial sand overlies aeolian limestone
7	Ys	Low sandy plain	Humic soil veneer overlying grey sand 1 m thick overlying marine limestone	Conforms to definition of Ys
8	Pg	Low undulating sandy plain	Dune sand (Safety Bay Sand) (1-8 m thick) overlying Becher Sand; calcrete 0.3 m thick, within 1 m of surface; thick humic soil at surface;limestone at 20-30 m	Degraded Holocene dunes of the Leschenault-Preston barrier overlying seagrass deposits
9	Ys	Low sandy plain	Quartz sand to 8-12 m; thin humic soil at surface	Part of a quartz sand sheet, buried by limestone on its western margin
10	Ysp	Wetland	Carbonate mud 3 m thick overlying indurated carbonate mud and soft carbonate mud to 6 m, which rests on limestone; surface mud locally calcretised to 10-20 cm	Wetland fill deposits
11	Ys	Stony plain	Humic soil 0.5 m thick overlying shelly marine limestone	Conforms to definition of Ys
12	Ys	Low sandy plain	Thin humic soil on yellow sand 1-2 m thick, overlying shelly marine limestone; limestone crops out at estuary shore where yellow sand cover has been stripped	More or less conforms to definition of Ys
13	Pg	Low undulating sandy plain	Thick humic soil overlying dune sand (1-5 m thick), overlying estuarine Leschenault Formation; thin calcrete sheet locally within 1 m of surface	Degraded Holocene dunes of Leschenault Peninsula barrier overlying estuarine deposits

[1] Formal stratigraphic nomenclature of units from Semeniuk (1983) and Semeniuk and Searle (1985b).

Similarly with the shoreline types in the Peel-Harvey estuary—much of the flat to plain estuary-fringing landforms have formed by late Holocene estuarine processes (Semeniuk & Semeniuk 1990) and should not be linked to landforms largely formed during the Pleistocene by coastal marine sedimentation and subsequent subaerial processes. This is particularly relevant when the estuarine plain landforms are not even connected or directly attached to the Pleistocene plain. That is, they cannot be directly traced into the Pleistocene unit, since there is an intervening high-relief ridge of the Spearwood Dunes separating the Pleistocene plain and the Holocene estuarine flats. Thus, again, use of the term Yoongarillup Plain by McArthur & Bartle (1980) on the margins of the Peel-Harvey estuary allocates Holocene landforms to a geomorphic unit defined as a plain underlain by very shallowly buried Pleistocene limestone. The same rationale applies to the other Holocene landforms which are flat, or undulating, or plains, that have been allocated to the system of the Yoongarillup Plain—they should not be considered as part of the Yoongarillup Plain.

The soils of the Yoongarillup Plain

There are two aspects that need to be addressed with regards to the soils of the Yoongarillup Plain—firstly the meaning and use of the term "association", and how it is applied to the surficial materials of this plain, and secondly, the validity and accuracy of the definitions and mapped distribution of the soils defined by McArthur & Bartle (1980).

Soils of the Yoongarillup Plain originally were defined to be an association by Churchward & McArthur (1980). An association consists of two or more soils occurring together in a characteristic pattern in a given geographic area; the soils should be distinguishable from each other, but on all except detailed soil maps, they should be grouped together because of their intricate areal distributions (Bates & Jackson 1987). On the other hand, Conacher & Dalrymple (1977) discuss in some detail the various uses and meanings of the term "soil association", noting that the soil-association concept has become the practical topographical mapping tool if only because uniformity of parent material is demanded. On these bases the soils of the Yoongarillup Association as described by McArthur & Bartle (1980) are not justified to be included into an encompassing group such as a soil association. The surficial materials referred to as soils are readily mapped as separate units. In addition, it should be noted that the soils are developed on markedly different physical and genetic geologic units, *ie* they have markedly different parent materials which are of diverse ages ranging from at least two stages of the Pleistocene to the middle and late Holocene (Table 1).

With regard to the accuracy of the mapping of the soils of the Yoongarillup Plain, it is evident that the soils as defined are incorrectly mapped or mis-identified in many situations. McArthur & Bartle (1980) do not provide a data base or location of sampling sites, and so it is difficult for subsequent investigators to revisit localities to resample, re-interpret, compare results, or propose alternative working hypotheses. It is not clear therefore whether their maps are based on a few soil sampling sites supplemented by aerial-photograph interpretation, or numerous systematically spaced field sample sites within each of the mapped units. Reliability diagrams also are not provided. Consequently, in order to compare the results and hypotheses of McArthur & Bartle (1980) with those of subsequent studies (*eg* Semeniuk 1990), it is necessary to select a portion of the terrain mapped by McArthur & Bartle (1980) and ground truth their terrain and soil designations. Therefore, four such small selected areas of landform-soil units drawn from the maps of McArthur & Bartle (1980), upon which are located the drill sites used in this study, are presented in Fig. 2.

Ideally, the map units and descriptions of McArthur & Bartle (1980) should be comparable with the descriptions of subsequent investigators. Information on the setting and stratigraphy of the various drill sites located in the various landform-soil units of McArthur & Bartle (1980) are presented in Table 1. It is evident that some of the drill site results either conform with the designated soil type for that locality (*eg* site 11), or are different from the stratigraphy and soils expected at the locality, but are not that markedly different to warrant wholesale exclusion from that nominated soil (*eg* site 12, which actually has 1-2 m rather than 0.3-0.4 m of quartz sand overlying fossiliferous limestone). However, the results from the remaining sites are markedly different from the landform-soil types that are designated for those sites (*eg* the landform-soil unit Ys at site 9, and the shallow stratigraphy of unit Pg at Leschenault Peninsula (site 13), the Leschenault-Preston barrier at Preston Beach (site 8), and along the Peel Inlet exchange channel at Mandurah (site 3).

It appears that a thin sheet of calcrete occurring at shallow depth at sites 3, 8 & 13 (Semeniuk & Meagher 1981b, Semeniuk & Searle 1983, and Semeniuk 1986) was interpreted by McArthur & Bartle (1980) to be Pleistocene limestone. This sheet of calcrete in the near-estuarine locations is developed on shell-bearing estuarine deposits formed at higher Holocene sealevel stands (Semeniuk & Semeniuk 1990), and therefore has shell incorporated into the calcrete, thus adding to the confusion between calcrete impregnated shelly Holocene sand and genuine shelly Pleistocene limestone. However, petrographic evidence in the calcretes, the full stratigraphic sequence above and below the calcrete, and radiocarbon ages demonstrate that the calcrete overprints and indurates Holocene deposits (Semeniuk & Semeniuk 1990). Holocene calcrete should not be confused with Pleistocene limestone.

Discussion

Comparison of data presented here with the work of McArthur & Bartle (1980) indicates that soil groups as defined within the Yoongarillup unit have been misapplied, and inaccurately mapped. These discrepancies lead to a number of conclusions and recommendations. Firstly, the term Yoongarillup Plain as a geomorphic entity should not be applied to incorporate all plains and flats in the Mandurah to Bunbury area. Rather, the term should be applied in a more restricted sense to refer to *the plain, with accompanying Pleistocene beachridge lines, between Mandurah and the northern part of Leschenault Inlet that is underlain by fossiliferous limestone mantled by a variable but relatively thin blanket of quartz sand.* In this context, the term is coincident with a fossil (Pleistocene), prograded beachridge plain that formed in a geographically restricted area between Mandurah and Bunbury behind a barrier limestone island chain as described by Semeniuk (1990). The topography, stratigraphy and sedimentological setting of the Pleistocene plain was similar to the Holocene Rockingham-Becher Plain as described by Searle *et al* (1988).

The term *Yoongarillup Plain* should not be applied to the low undulating terrains and plains developed within the Quindalup Dunes, or to shoreline landforms of the Peel-Harvey system developed by estuarine processes. A new term for the estuarine geomorphic systems is warranted; I suggest that the term *Vasse Estuarine System* be used (not Vasse Estuarine and Lagoonal System, as suggested by Wells and Hesp, undated). With regard to the wetlands, it is arguable whether they should be regarded as part of the Yoongarillup Plain in its suggested re-definition above, or as separate geomorphic units. It may be preferable to leave the wetlands as part of an assemblage of terrain types within the Yoongarillup Plain, because in reality some are a system of depressions within the plain, but final resolution of this matter must await future work.

With regard to the soil groups, I suggest that the term *Yoongarillup Association* be applied to surficial materials underlying the Yoongarillup Plain as defined in this paper, and that the surficial materials underlying the Quindalup Dunes, the estuarine fringes, and the other geomorphic units in the region be excluded from the Yoongarillup Association. The surficial materials bordering the Peel-Harvey estuary are more aptly incorporated into the Vasse unit of Churchward & McArthur (1980), and those occurring in the Quindalup system are more aptly referred to the Quindalup Association. Finally, I suggest that a rigorous re-mapping of soil association units be undertaken in the Mandurah-Bunbury area. However, in the future, before landform-soil units are erected and mapped, attention should be paid to features such as calcretes and humic soils, the separation of primary and secondary features in the surficial materials, the lithostratigraphic sequence as the basis of identifying parent materials for soils, the age structure of stratigraphic sequences underlying the various landforms, and the evolutionary processes leading to the development of the various landforms and soils.

Some of the mapping suggested above has already commenced (*cf* Gozzard 1987; Wells & Hesp, undated). Gozzard (1987) has carried out mapping of geomorphic units (landform units) in parts of this region. Gozzard (1987) clearly separates the Yoongarillup Plain unit from the Spearwood Dunes and estuarine units, and also differentiates the various geomorphic components (such as dune ridge lines) within the Yoongarillup Plain.

Wells and Hesp (undated), however, in their mapping of landform and soil units, have abandoned the term Yoongarillup Plain, and refer to the low-lying plain area of fossiliferous limestone in the region as "Spearwood Dune and Plain System"—a procedure I do not support, in that it aggregates a plain unit with a dune unit only because they both are underlain by Pleistocene limestone. The term Spearwood Dune should be applied to terrain comprised of Pleistocene dunes (aeolianite) that are similar to those in the coastal region of Perth, and not to a time-rock unit, or to a formational unit. The plain between Mandurah and Bunbury is not similar to the terrain of the Spearwood Dunes as evident in the type area of Spearwood, and the allocation of this plain to the Spearwood Dunes and the subsequent re-definition of the Spearwood Dunes to incorporate limestone plains is unacceptable. To adequately differentiate the markedly different geomorphic entities on the Swan Coastal Plain, for purposes of landform mapping and for unravelling the Quaternary history, the Yoongarillup Plain needs to be separated from the Spearwood Dunes.

Other aspects of the mapping by Wells and Hesp (undated) similarly are problematical. While they separate the limestone plain from the estuarine units, they aggregate these estuarine units with wetland/lagoonal/lacustrine units, and river units. Estuarine units should be separated from the wetland/lagoonal/lacustrine units. The riverine units are normally referred to the Pinjarra Plain, but these authors do not use the term Pinjarra Plain for riverine flats and plains that are proximal to the Peel-Harvey estuary. Many of the map units of Wells and Hesp (undated) also are incompatible with the drilling results of Semeniuk & Semeniuk (1990), and the drill data presented by Gozzard (1987). For instance, the map units V1 and V6 along the northern edge of Peel Inlet is inconsistent with aerial photograph information and the mapping and drilling results of Semeniuk & Semeniuk (1990). Finally, there is no reliability diagram, or map of sampling sites provided by Wells and Hesp (undated), to assess the reliability of their map units.

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